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Phosphorus and Nitrogen in Runoff Following Beef Cattle Manure of Compost Application

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Surface Water Quality

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Bahman Eghball* and John E. Gilley

ABSTRACT

Manure or compost from beef cattle feedlots can be an excellent sources of nutrients and organic matter when added to soils, but they can also pollute runoff. We determined the effects of simulated rainfall on runoff losses of P and N, and EC and pH following application of manure and compost to a Sharpsburg silty clay loam (fine smectitic, mesic Typic Argiudoll) soil having grain sorghum [*Sorghum bicolor* (L.) Moench] and winter wheat (*Triticum aestivum* L.) residues. Manure, compost, and fertilizer were applied to no-till fields at rates required to meet N or P requirements for corn (*Zea mays* L.) production and were either left on the soil surface or disked to 8 cm. There were also untreated checks. Runoff concentrations of dissolved P (DP), bioavailable P (BAP), and NH_4–N were significantly greater when the soil was not disked. Total and particulate P concentrations in runoff were generally less under wheat than sorghum residue and were less for the no-till than the disked condition. In the disked system, N or P-based manure or compost application resulted in DP concentration <1 mg L^{-1}. Manure and compost application resulted in greater runoff EC values than fertilizer application. Phosphorus concentration of runoff receiving P fertilizer or N-based manure and compost application can be an environmental concern when these sources are applied under no-till conditions without incorporation.

Beef cattle feedlot manure and composted manure are valuable resources that can be effectively used for crop production and soil improvement. Manure or compost contain essential nutrients for plant growth. Soil organic matter (an ion exchange material, chelating agent, buffering material, and important factor in soil aggregation) can also be increased by the addition of beef cattle feedlot manure or compost (Eghball and Power, 1994).

Beef cattle feedlot manure and composted feedlot manure can be applied for crop production under no-till conditions. Eghball and Power (1999a) found that in 3 out of 4 yr, manure or compost applied to a no-till cropping system resulted in the same corn yield as manure or compost applied to a conventional tillage system. This is because about 50% of the excreted N in the cattle feedlot is lost by the time manure is collected (Gilbertson et al., 1971). The remaining N is in stable forms and contains little NH_4–N, which is subject to volatilization loss. Composted feedlot manure also contains little NH_4–N and the N compounds are stable since up to 40% of N is lost in the composting process (Eghball et al., 1997).

In the USA, no-till crop production systems are becoming more common. In 1996, 41% of the planted hectares in the USA were under no-till or reduced tillage systems (CTIC, 1997). Soil protection from erosion losses, conservation of soil water by increased infiltration and decreased evaporation, increased use of land too steep for conventional tillage production, and reduction in fuel, labor, and machinery costs are among the reasons for increased use of reduced tillage systems (Doran and Linn, 1994).

Manure application to no-till land can result in increased residue on the surface and may reduce soil erosion. Woodruff et al. (1974) showed that manure application could reduce soil wind erosion whereas Gilley and Eghball (1998) found that N or P-based manure or compost application resulted in similar rates of runoff and soil water erosion as in the untreated check treatment for both no-till and disked systems. Erosion from disked soil however, was greater than from no-till soil regardless of application of manure, compost, fertilizer, or no treatment. Manure application to no-till without incorporation may reduce its effectiveness as a nutrient source because of potential N loss.

Environmental pollution may occur when manure or compost is applied to soil. Runoff from cropland areas receiving manure or compost may contribute to increased P and N concentrations in streams and lakes. Even though P from manure application may move deep into the soil (Eghball et al., 1996), the primary concern about P pollution is the eutrophication of surface waters. The main factors controlling P movement in surface runoff are transport (runoff and erosion) and source factors such as manure or fertilizer application and soil P test level (Pote et al., 1996; Sharpley et al., 1993). Beef cattle feedlot manure applications <7 Mg dry wt. ha^{-1} usually do not contribute to P or N enrichment of surface waters on level soils (Jones and Willis, 1995). Mueller et al. (1984) found that application of 8 Mg ha^{-1} (dry wt.) dairy manure resulted in significantly greater dissolved and bioavailable P loss in no-till as compared to a conventional system. The bioavailable P loss followed the order no-till > conventional = chisel.

Ammonium loss into surface waters can result in poisoning of aquatic organisms if the concentration is >2.5 mg L^{-1} (USEPA, 1986). Nitrate in runoff from fields receiving manure, compost, or fertilizer may be carried

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Abbreviations: DP, dissolved phosphorus; BAP, bioavailable phosphorus; PP, particulate phosphorus; EC, electrical conductivity.

Table 1. Nitrogen and P concentrations of applied manure and compost (dry weight basis) in 1996 and 1997.

Source	1996					1997				
	Dissolved P	NO_3–N	NH_4–N	Total P	Total N	Dissolved P	NO_3–N	NH_4–N	Total P	Total N
	mg kg^{-1}			g kg^{-1}		mg kg^{-1}			g kg^{-1}	
Manure	271	26	531	4.48	7.65	314	4	125	4.36	7.93
Compost	145	1205	24	2.86	6.02	184	316	311	5.52	9.77

to rivers and lakes. The elevated NO_3 level in the Gulf of Mexico may contribute to the hypoxia condition that is a zone depleted of oxygen and marine life.

The differences in environmental consequences of beef cattle feedlot manure and composted manure application to no-till and disked conditions are not known. Little information is available on the effects of N or P-based manure or compost application on runoff P and N concentrations. The objective of this study was to determine the effects of N or P-based applications of beef cattle manure or composted manure on runoff concentrations of dissolved P, bioavailable P, particulate P, total P, nitrate–N, ammonium–N, total N, and pH and EC levels from fields under no-till and disked conditions.

MATERIALS AND METHODS

This study was conducted on a Sharpsburg silty clay loam soil at the University of Nebraska Rogers Memorial Farm in Lancaster County, approximately 18 km east of Lincoln, NE. The soil consisted of 11% sand, 54% silt, and 35% clay and 18.5 mg kg^{-1} organic C in the top 15 cm. The area had been cropped for several years as part of a no-till management system that used a grain sorghum, soybean [*Glycine max* (L.) Merr], winter wheat crop sequence. Two rainfall simulation experiments were conducted on a soil with either sorghum residue (1996) or winter wheat residue (1997). The experimental methods were selected to simulate conditions that exist in the spring when manure, compost, or fertilizer are typically applied. However, there was no history of manure or compost application to this site.

A portable rainfall simulator based on a design by Swanson (1965) was used to apply rainfall simultaneously to two plots. Each 3.7 m wide by 10.7 m long plot was established using sheet metal borders. Weed control was achieved by herbicide application during the study period. An initial 1-h rainfall application at an intensity of approximately 6.4 cm h^{-1} was made at existing soil-water conditions. A second 1-h application (wet run) was conducted approximately 24 h later. The plots were covered with plastic between the initial and wet runs to eliminate the input of natural rainfall into the system. For additional information regarding runoff and erosion measurements in these experiments, see Gilley and Eghball (1998).

A trough extending across the bottom of each plot gathered runoff, which was measured using a flume with a stage recorder. Runoff samples were collected in plastic bottles at 5-min intervals from each trough. Runoff samples collected 5, 10, 15, 30, and 60 min after initiation of rainfall from each plot were centrifuged, filtered, and analyzed for dissolved P (Murphy and Riley, 1962), and NO_3–N, and NH_4–N concentration using a Lachat (Zellweger Analytics, Milwaukee, WI) system. Noncentrifuged samples were analyzed for total P (Johnson and Ulrich, 1959) and total N (Tate, 1994) concentration, and measurement of pH and electrical conductivity. Particulate P was calculated by the difference between total P and DP. Bioavailable P (BAP) in runoff samples was measured using iron oxide-impregnated paper strips (Menon et al., 1990; Sharpley, 1993).

Analysis of variance was used to determine differences between tillage systems and fertility treatments. Because of nonnormality and large variability of the P and N parameters, these values were transformed using log (parameter +10) (Steel and Torrie, 1980). Analysis of variance was performed on the transformed data. In these analyses, time of runoff sampling was considered a subsample. A probability level $\leq$0.10 was considered significant.

Sorghum Residue Study

This portion of the study was conducted from June to August of 1996 as a split-plot in a randomized complete block design with three replications. Sorghum grain yield in 1995 was 4.9 Mg ha^{-1}. No-till and disked systems were the main plots and subplots consisted of the following six treatments: (i) Beef cattle feedlot manure applied at a rate of 49.4 Mg dry weight ha^{-1} to meet corn N requirements (151 kg N ha^{-1}), (ii) manure applied at a rate of 11.5 Mg dry wt. ha^{-1} to meet corn P requirements (25.5 kg P ha^{-1}) plus 104 kg N ha^{-1} as ammonium nitrate, (iii) composted beef feedlot manure

Table 2. Nitrogen and P concentrations and pH and EC of the soil before manure and compost application in three experimental blocks for the 1996 and 1997 experiments.

Year block	0–5 cm soil						5–15 cm soil					
	WSP†	BKP	NO_3–N	NH_4–N	EC‡	pH	WSP	BKP	NO_3–N	NH_4–N	EC	pH
	mg kg^{-1}				d S m^{-1}		mg kg^{-1}				d S m^{-1}	
1996												
1	1.0	24.6	20.5	5.9	0.5	5.3	0.6	11.6	8.8	5.7	0.4	5.1
2	1.3	31.4	25.6	5.0	0.5	5.2	0.7	13.0	7.4	5.2	0.3	5.1
3	1.7	38.0	28.8	5.8	0.5	5.2	0.6	14.5	8.3	5.1	0.3	5.0
1997												
1	7.7	78.9	44.4	17.2	0.6	5.5	2.6	23.0	29.2	6.0	0.5	5.0
2	6.6	70.0	49.2	16.7	0.6	5.7	0.6	12.0	22.8	5.2	0.4	4.9
3	6.0	79.4	54.7	10.7	0.6	5.5	0.7	13.6	30.4	4.4	0.4	4.9

† WSP is water soluble P and BKP is Bray and Kurtz no. 1.

Table 3. Effects of tillage and treatment on runoff concentration of dissolved P (DP), bioavailable P (BAP), particulate and total P, nitrate–N, ammonium–N, electrical conductivity (EC), and pH during the initial simulation rainfall run in a field with sorghum residue in 1996.

Variable†	DP	BAP	Particulate P	Total P	NO_3–N‡	NH_4–N	EC	pH
	mg L^{-1}						d S m^{-1}	
Tillage								
No-till	2.50	3.39	7.6	10.1	27.0	9.3	0.87	7.4
Disked	0.28	1.30	10.5	10.8	46.8	2.9	0.91	6.9
Treatment								
Compost N	1.68	3.63	16.7	17.2	56.6	0.1	1.28	7.2
Compost P	0.64	1.75	8.1	8.7	47.5	7.3	0.92	7.3
Manure N	1.53	2.60	9.9	11.5	23.3	7.1	0.87	7.1
Manure P	0.73	1.47	6.9	7.7	39.8	13.0	0.89	7.0
Fertilizer	5.20	5.33	8.6	13.8	33.0	11.9	0.76	7.1
Check	0.11	0.64	5.8	5.9	21.1	0.1	0.70	7.5
Analysis of variance§					PR > *F*			
Replication	0.14	0.02	0.01	0.01	0.33	0.01	0.71	0.01
Tillage	0.01	0.01	0.27	0.78	0.01	0.02	0.35	0.14
Replication × tillage								
Treatment	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Manure vs. compost	0.65	0.19	0.05	0.09	0.01	0.01	0.01	0.04
Fertilizer vs. man. & com.	0.01	0.01	0.29	0.01	0.01	0.01	0.01	0.05
Compost N vs. compost P	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.88
Manure N vs. manure P	0.25	0.22	0.07	0.06	0.01	0.01	0.13	0.09
Check vs. others	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Time (treatment)	0.01	0.01	0.99	0.99	0.01	0.01	0.01	0.06
Tillage × treatment	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.62
CV, %	4.1	4.4	7.0	7.8	6.2	7.3	17.1	7.0

† Arithmatic average of five sampling times for each plot.
‡ Irrigation water had an average NO_3–N concentration of 21 mg L^{-1}.
§ Analysis of variance was performed on the transformed data (log parameter + 10) for all parameters except EC and pH. Actual data was used for the analysis of EC and pH.

applied at a rate of 125.6 Mg dry wt. ha^{-1} to meet corn N requirements, (iv) compost applied at a rate of 18.0 Mg dry wt. ha^{-1} to meet corn P requirements plus 116 kg N ha^{-1}, (v) inorganic commercial fertilizer applied at rates of 151 kg N ha^{-1} and 25.5 kg P ha^{-1} as ammonium nitrate 34–0–0 (N–P–K) and 18–20–0 (N–P–K), respectively, and (vi) untreated check. Fully processed and cured compost was used in both studies. The total amount of N for the treatments 1, 2, 3, and 4 were 377, 88, 756, and 108 kg N ha^{-1}, respectively. Corresponding values for total P application were 221, 51, 359, and 51 kg P ha^{-1}, respectively. Nitrogen and P concentrations of manure and compost are given in Table 1. It was assumed that the

Table 4. Effects of tillage and treatment on runoff concentration of dissolved P (DP), bioavailable P (BAP), particulate and total P, nitrate–N, ammonium–N, electrical conductivity (EC), and pH during the wet simulation rainfall run on a field with sorghum residue in 1996.

Variable†	DP	BAP	Particulate P	Total P	NO_3–N†	NH_4–N	EC	pH
	mg L^{-1}						d S m^{-1}	
Tillage								
No-till	1.05	2.06	5.5	7.3	23.6	3.8	0.84	7.6
Tilled	0.26	1.15	9.7	10.0	23.8	1.3	0.76	7.2
Treatment								
Compost N	1.33	3.18	12.4	13.8	25.7	0.2	0.89	7.4
Compost P	0.41	1.12	6.3	6.7	25.5	3.3	0.78	7.5
Manure N	1.18	2.73	8.8	9.9	21.2	4.0	0.83	7.3
Manure P	0.35	1.06	5.5	5.8	25.7	4.1	0.78	7.5
Fertilizer	0.40	0.84	7.7	10.4	22.5	3.4	0.78	7.1
Check	0.15	0.42	5.3	5.4	21.4	0.3	0.73	7.6
Analysis of variance§					PR> *F*			
Replication	0.01	0.01	0.01	0.01	0.35	0.01	0.01	0.01
Tillage	0.02	0.03	0.03	0.13	0.75	0.03	0.06	0.22
Replication × tillage								
Treatment	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Manure vs. compost	0.04	0.01	0.01	0.01	0.01	0.01	0.03	0.27
Fertilizer vs. man. & com.	0.01	0.01	0.06	0.42	0.01	0.01	0.07	0.01
Compost N vs. compost P	0.01	0.01	0.01	0.01	0.59	0.01	0.01	0.53
Manure N vs. manure P	0.01	0.01	0.01	0.01	0.01	0.80	0.06	0.04
Check vs. others	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Time (treatment)	0.01	0.37	0.61	0.80	0.39	0.03	0.21	0.99
Tillage × treatment	0.01	0.01	0.01	0.01	0.16	0.01	0.44	0.49
CV, %	1.2	1.8	4.7	5.9	3.2	3.9	11.5	5.9

† Arithmatic average of five sampling times for each plot.
‡ Irrigation water had an average NO_3–N concentration of 21 mg L^{-1}.
§ Analysis of variance was performed on the transformed data (log parameter + 10) for all parameters except EC and pH. Actual data was used for the analysis of EC and pH.

plant N availability from manure and compost was 40 and 20%, respectively, in the year of application (Gilbertson et al., 1979). Phosphorus availability from manure or compost was assumed to be 50% in the year of application based on our experience.

Manure, compost, and fertilizer were applied by hand at the above rates that were required to produce a corn crop with a target yield of 9.4 Mg ha^{-1}. On the no-till plots, the manure, compost, and fertilizer were left undisturbed on the soil surface. A single disking operation to a depth of approximately 7.5 cm was performed up and down the slope on the disked treatments to incorporate the manure, compost, and fertilizer. The top 7.5 cm of the soil had a bulk density of 1.3 Mg m^{-3} in the no-till and 1.1 Mg m^{-3} in the disked plots. The disking operation was the first tillage that had occurred on the study site in several years. A single disking operation is not representative of a normal conventional tillage system in this region. A variety of crops could have been chosen to follow sorghum. Corn was selected because it is grown extensively in the area and it has a relatively large nutrient requirement. By applying large amounts of manure, compost, or fertilizer, to provide for corn nutrient requirements, there was an increased opportunity to study extreme situations.

Irrigation water had a NO_3–N concentration of 21 mg L^{-1} and a dissolved P concentration of 0.25 mg L^{-1}. Soil characteristics of the experimental site are given in Table 2.

Wheat Residue Study

The investigation involving wheat residue was conducted in July and August 1997. The study area was left undisturbed and fallow following wheat harvest in the summer of 1996. Winter wheat grain yield in 1996 was 2.2 Mg ha^{-1}. A split-plot in a randomized complete block design with three replications (24 total plots) was used in this investigation. Main plots consisted of no-till and disked conditions and subplots included the following four treatments: (i) manure applied at a rate of 47.7 Mg dry weight ha^{-1} to meet corn N requirements (151 kg N ha^{-1}); (ii) compost applied at a rate of 77.5 Mg dry wt. ha^{-1} to meet corn N requirements; (iii) inorganic commercial fertilizer applied at a rate of 151 kg N ha^{-1} and 25.5 kg P ha^{-1}; and (iv) untreated check. The total amount of N applied was 378 kg N ha^{-1} for manure and 757 kg N ha^{-1} for compost. Total amount of P applied was 208 kg P ha^{-1} for the manure and 428 kg P ha^{-1} for the compost treatment. Nitrogen availability assumptions were similar to those in the sorghum residue study.

The manure, compost, and fertilizer were applied by hand

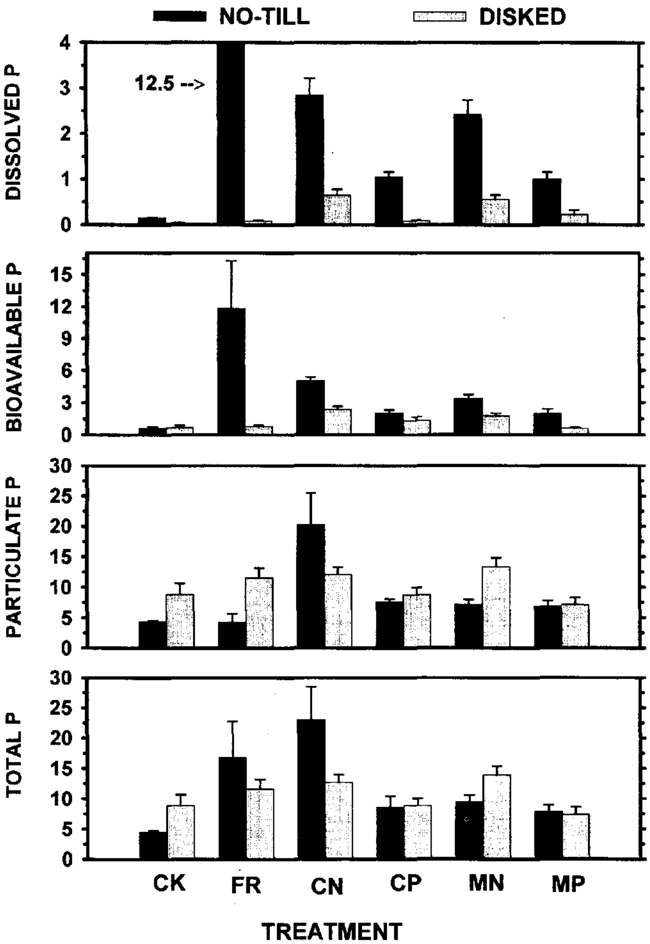

Fig. 1. Runoff concentration (mg L^{-1}) of dissolved, bioavailable, particulate, and total P for six fertility treatments and two tillage systems during the initial rainfall simulation run on the sorghum residue study. CK is check, FR is fertilizer, CN is compost for corn N needs, CP is compost for corn P needs, MN is manure for N, and MP is manure for P. Vertical bars are standard errors (2 SE indicates 0.95 and 1.55 SE indicates 0.90 probability level).

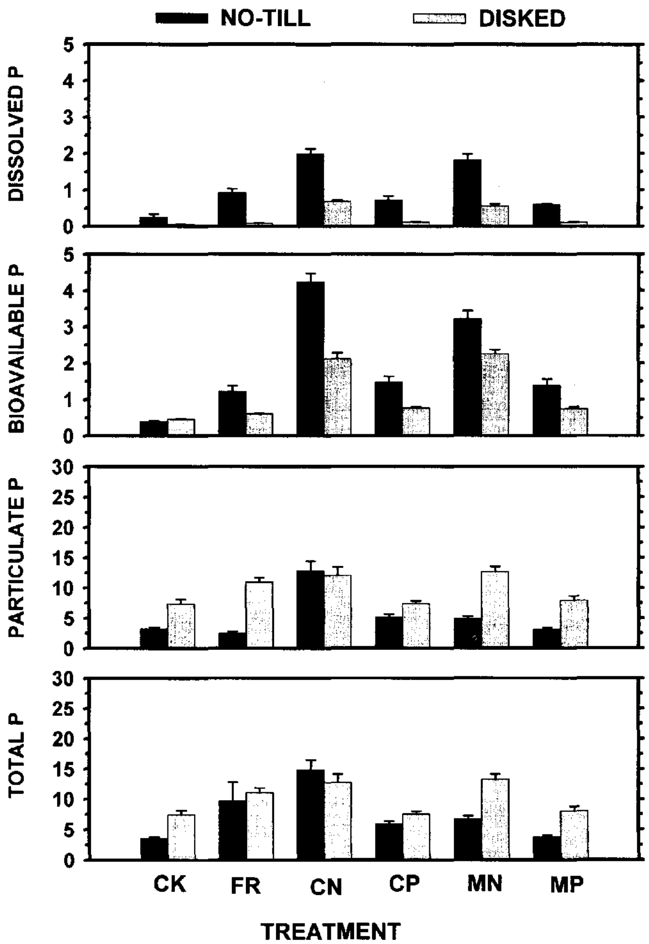

Fig. 2. Runoff concentration (mg L^{-1}) of dissolved, bioavailable, particulate, and total P for six fertility treatments and two tillage systems during the wet rainfall simulation run on the sorghum residue study. CK is check, FR is fertilizer, CN is compost for corn N needs, CP is compost for corn P needs, MN is manure for N, and MP is manure for P. Vertical bars are standard errors (2 SE indicates 0.95 and 1.55 SE indicates 0.90 probability level).

Table 5. Runoff concentration of dissolved P (DP), bioavailable P (BAP), nitrate–N and ammonium–N at different times during the simulation rainfall runs in 1996 averaged across tillage and treatments.

	Initial run				Wet run			
Time	DP	BAP	NO_3–N	NH_4–N	DP	BAP	NO_3–N†	NH_4–N
min	mg L^{-1}							
5	–	–	–	–	0.45 c	1.39 b	22.2 b	2.3 bc
10	0.6 d‡	1.8 c	33.6 ab	13.3 a	0.78 a	1.74 a	23.5 ab	3.2 a
15	3.0 a	3.9 a	31.2 b	10.6 b	0.72 ab	1.56 ab	23.1 b	3.1 a
30	1.8 b	2.7 b	35.3 ab	6.3 c	0.67 ab	1.61 ab	24.4 a	2.4 b
45	1.2 c	2.0 c	40.8 a	5.5 cd	0.67 ab	1.71 a	24.4 a	2.1 bc
60	1.0 cd	2.0 c	34.4 ab	4.3 d	0.59 b	1.52 ab	24.8 a	1.9 c

† Irrigation water had an average NO_3–N concentration of 21 mg L^{-1}.
‡ Values with different letters are significantly different at 0.10 probability level based on Duncan's Multiple Range Test.

just before the rainfall simulation tests at the above rates that were required to produce a corn crop with a target yield of 9.4 Mg ha^{-1}. The manure and compost application, tillage methods and simulation runs were similar to those for the sorghum residue study. The top 7.5 cm soil had a bulk density of 1.3 Mg m^{-3} in the no-till and 1.1 Mg m^{-3} in the disked plots. Irrigation water had an average NO_3–N concentration of 23 mg L^{-1} and a dissolved P concentration of 0.22 mg L^{-1}. Manure and compost N and P concentrations are given in Table 1 and soil characteristics are presented in Table 2.

RESULTS AND DISCUSSION

Sorghum Residue Study

The mean slope for the study area was 7%, while slope of individual plots ranged from 5 to 9%. Slope varied little within a given experimental block. Mean residue covers at the time of rainfall simulation for the no-till and disked treatments were 46 and 23%, respectively. Thus, the single disking operation reduced mean residue cover by 50%. Information about runoff and erosion from these studies are given in Gilley and Eghball (1998).

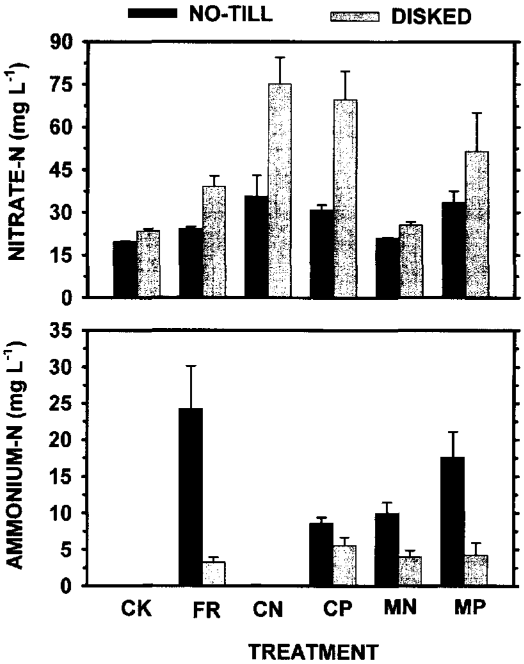

Fig. 3. Runoff concentration of NO_3 –N and ammonium–N for six fertility treatments and two tillage systems during the initial rainfall simulation run on the sorghum residue study. CK is check, FR is fertilizer, CN is compost for corn N needs, CP is compost for corn P needs, MN is manure for N, and MP is manure for P. Irrigation water had an average NO_3–N concentration of 21 mg L^{-1}. Vertical bars are standard errors (2 SE indicates 0.95 and 1.55 SE indicates 0.90 probability level).

Runoff concentrations of DP, BAP, and NH_4–N were significantly greater for the no-till than disked condition during both simulated rainfall runs (Table 3). However, NO_3–N concentration was significantly less for no-till than disked condition during the initial run (Table 3). Apparently, the high NO_3–N concentration of the surface soil (Table 2) contributed to an increase in runoff

Table 6. Effects of tillage and treatment on total amounts of dissolved P (DP), bioavailable P (BAP), particulate and total P, nitrate–N, and ammonium–N in runoff during initial and wet simulation rainfall runs in a field with sorghum residue in 1996.

Variable	DP	BAP	Particulate P	Total P	NO_3–N†	NH_4–N
	kg ha^{-1}					
Initial run						
Tillage						
No-till	0.35 a†	0.46 a	1.08 a	1.44 a	3.23 a	1.30 a
Disked	0.04 b	0.15 b	1.11 a	1.14 a	5.22 a	0.32 b
Treatment						
Compost N	0.20 b	0.42 ab	2.02 a	2.21 a	7.45 a	0.01 b
Compost P	0.08 b	0.22 bc	1.00 b	1.04 bc	5.92 ab	0.89 ab
Manure N	0.21 b	0.35 bc	1.35 ab	1.56 abc	3.09 bc	1.02 ab
Manure P	0.09 b	0.18 bc	0.68 b	0.77 bc	3.47 bc	1.48 a
Fertilizer	0.64 a	0.66 a	1.09 ab	1.73 ab	4.14 abc	1.47 a
Check	0.01 b	0.05 c	0.46 b	0.47 c	1.45 c	0.00 b
Wet run						
Tillage						
No-till	0.36 a	0.69 a	1.81 b	2.18 b	7.50 a	1.32 a
Disked	0.09 b	0.37 b	3.08 a	3.17 a	7.31 a	0.45 b
Treatment						
Compost N	0.42 a	0.99 a	3.88 a	4.31 a	7.75 a	0.05 b
Compost P	0.16 b	0.41 b	2.21 bc	2.37 c	9.65 a	1.28 a
Manure N	0.46 a	1.06 a	3.43 ab	3.88 ab	8.06 a	1.62 a
Manure P	0.10 b	0.29 bc	1.43 c	1.53 c	6.81 ab	1.15 a
Fertilizer	0.12 b	0.27 bc	2.59 abc	2.71 bc	7.28 ab	1.09 a
Check	0.05 b	0.10 c	1.27 c	1.32 c	4.83 b	0.10 b

† Within tillage or treatment of each run, values with different letters are significantly different at 0.10 probability level based on Duncan's Multiple Range Test.

Table 7. Effects of tillage and treatment on runoff concentration of dissolved P (DP), bioavailable P (BAP), particulate and total P, nitrate–N, ammonium–N, total N, electrical conductivity (EC), and pH during the initial simulation rainfall run on a field with wheat residue in 1997.

Variable†	DP	BAP	Particulate P	Total P	NO_3–N‡	NH_4–N	Total N	EC	pH
	mg L^{-1}							d S m^{-1}	
Tillage									
No-till	3.76	4.21	0.7	4.5	30.6	9.8	107.8	0.96	7.3
Tilled	0.18	0.43	5.6	5.8	25.6	0.9	108.2	0.74	7.4
Treatment									
Compost	1.75	2.12	4.2	5.9	37.7	6.2	101.7	0.99	7.3
Manure	1.71	2.21	3.0	4.8	24.6	6.8	98.5	0.92	7.3
Fertilizer	4.80	5.24	0.0	4.7	26.6	9.2	126.2	0.78	7.4
Check	0.07	0.15	4.9	5.0	23.7	0.1	106.1	0.73	7.4
Analysis of variance§					PR > *F*				
Replication	0.01	0.01	0.26	0.01	0.75	0.08	0.01	0.02	0.01
Tillage	0.07	0.07	0.05	0.13	0.25	0.01	0.66	0.02	0.42
Replication × tillage									
Treatment	0.01	0.01	0.24	0.01	0.01	0.01	0.04	0.01	0.07
Check vs. others	0.01	0.01	0.28	0.88	0.01	0.01	0.36	0.01	0.19
Fertilizer vs. man. & com.	0.11	0.20	0.11	0.26	0.02	0.15	0.01	0.01	0.03
Manure vs. compost	0.60	0.66	0.45	0.01	0.01	0.44	0.96	0.01	0.72
Time (treatment)	0.76	0.81	0.28	0.67	0.71	0.85	0.25	0.29	0.73
Tillage × treatment	0.01	0.01	0.01	0.44	0.01	0.01	0.01	0.01	0.01
CV, %	6.3	6.6	18.1	4.3	3.3	7.9	7.1	9.6	2.0

† Arithmatic average of five sampling times for each plot.
‡ Irrigation water had an average NO_3–N concentration of 23 mg L^{-1}.
§ Analysis of variance was performed on the transformed data (log parameter +10) for all parameters except EC and pH. Actual data was used for the analysis of EC and pH.

NO_3–N concentration when the soil was disked. Nitrate–N concentrations of runoff were similar for the two tillage systems during the wet run indicating that most of the NO_3–N of the surface soil was carried in runoff during the initial run (Table 4). Total P concentration was not influenced by tillage in either simulation runs (Tables 3 and 4). Loss of particulate P from the disked treatment was greater than the no-till treatment during the wet run. Averaged across treatments, NH_4–N concentration in runoff from the no-till plots was greater than the critical 2.5 mg L^{-1} during both simulation runs (Tables 3 and 4). Ammonium–N concentration >2.5 mg L^{-1} may be harmful to fish (USEPA, 1973). Averaged across treatments, there was no significant effect of tillage on runoff pH values during either simulation run (Tables 3 and 4).

Fertility treatments significantly influenced runoff concentration of all P and N parameters, and EC and pH values during both simulation runs (Tables 3 and 4). There were significant tillage by treatment interactions for all parameters (except pH) during the initial run (Table 3). There also were significant tillage by treatment interactions for all the P parameters and NH_4–N during the wet run (Table 4). Runoff concentra-

Table 8. Effects of tillage and treatment on runoff concentration of dissolved P (DP), bioavailable P (BAP), particulate and total P, nitrate–N, ammonium–N, total N, electrical conductivity (EC), and pH during the wet simulation rainfall run on a field with wheat residue in 1997.

Variable†	DP	BAP	PP	Total P	NO_3–N‡	NH_4–N	Total N	EC	pH
	mg L^{-1}							d S m^{-1}	
Tillage									
No-till	1.39	1.59	2.3	3.7	27.1	4.8	93.9	0.87	7.3
Tilled	0.18	0.48	7.0	7.2	23.8	0.8	83.3	0.77	7.3
Treatment									
Compost	1.36	1.78	3.6	5.0	30.4	3.6	86.6	0.90	7.3
Manure	1.30	1.68	4.0	5.4	23.5	4.1	88.4	0.86	7.2
Fertilizer	0.37	0.44	5.5	5.9	25.0	3.3	91.1	0.77	7.4
Check	0.09	0.24	5.5	5.6	22.9	0.1	88.1	0.75	7.4
Analysis of variance§					PR > *F*				
Replication	0.01	0.01	0.04	0.15	0.01	0.17	0.01	0.42	0.01
Tillage	0.02	0.01	0.07	0.09	0.11	0.01	0.67	0.04	0.45
Replication × tillage									
Treatment	0.01	0.01	0.01	0.40	0.01	0.01	0.85	0.01	0.01
Check vs. others	0.01	0.01	0.01	0.43	0.01	0.01	0.49	0.01	0.01
Fertilizer vs. man. & com.	0.01	0.01	0.01	0.17	0.01	0.09	0.82	0.01	0.01
Manure vs. compost	0.46	0.29	0.55	0.52	0.01	0.14	0.61	0.01	0.21
Time (treatment)	0.01	0.01	0.90	0.92	0.95	0.15	0.99	0.03	0.80
Tillage × treatment	0.01	0.01	0.10	0.67	0.01	0.01	0.03	0.01	0.01
CV, %	1.3	1.5	8.3	7.8	1.7	3.5	7.6	6.0	1.3

† Arithmatic average of five sampling times for each plot.
‡ Irrigation water had an average NO_3–N concentration of 23 mg L^{-1}.
§ Analysis of variance was performed on the transformed data (log parameter +10) for all parameters except EC and pH. Actual data was used for the analysis of EC and pH.

tion of DP and BAP were greater for no-till than the disked condition for the manure, compost and fertilizer treatments during both simulation runs, but the magnitude of the differences varied among treatments (Fig. 1 and 2). In some parts of the country, a flow-weighted-annual DP runoff concentration of 1 mg L^{-1}, similar to that required of sewage treatment plants, has been proposed for agricultural runoff (USEPA, 1986). Runoff DP concentrations were below 1 mg L^{-1} for all treatments in the disked soil during both runs (Fig. 1 and 2). Runoff DP concentration for N-based manure and compost treatments in the no-till were significantly >1 mg L^{-1}, but DP for the P-based treatments were not different than 1 mg L^{-1} during both simulation runs (Fig. 1 and 2). Eghball and Power (1999b) found that P-based manure or compost application resulted in similar corn grain yields as those for N-based or fertilizer applications but with significantly less P build-up in the top 150 mm soil. The results of this study indicate that N-based manure or compost application in no-till will result in P pollution of surface waters, unlike P-based application.

Concentrations of DP and BAP were significantly greater for the fertilizer treatment than the N or P-based manure and compost treatments in the no-till during the initial run, but were less than N-based manure or compost during the wet run (Fig. 1 and 2). This indicates that the loss of P from heavy manure or compost application will continue over a longer time period than from fertilizer application since the amount of P applied was greater for N-based manure or compost application than the fertilizer.

For both simulation runs, particulate P and total P concentrations were generally greater for disked than the no-till condition except compost for N treatment (Fig. 1 and 2), indicating that greater soil loss in the soil resulted in greater amounts of particulate and total P being carried by runoff. Runoff NO_3–N concentration was greater for the disked than the no-till condition for all treatments but this was reversed for ammonium–N (Fig. 3). This was apparently because the NO_3–N concentration of the surface 50 mm of soil was high (Table 2) and disking disturbed the soil and enhanced runoff loss of NO_3–N. Ammonium is relatively immobile and generally followed the same trend as DP. Sharpley et al. (1985) found that the NO_3 concentration of the top 0 to 50 mm soil did not have a significant effect on runoff NO_3 concentration but the 0 to 50 mm soil concentrations of DP, PP, and total N had a significant effect on losses of these parameters.

The runoff EC values were greater for compost plots than those from manured or fertilized plots during the initial run (Table 3). Runoff pH values were greater for check than manure, compost, or fertilizer application during the initial and wet runs (Table 3).

Concentration of DP, BAP, and ammonium–N tended to decrease with time after runoff initiation during both simulation runs (Table 5). Runoff NO_3–N concentration tended to increase with time after runoff initiation (Table 5).

Total runoff loads of N and P during both simulation runs are given in Table 6. The trends for the load of nutrients in runoff were similar to those of concentration for all parameters except for NO_3 during the initial run (Tables 3 and 6).

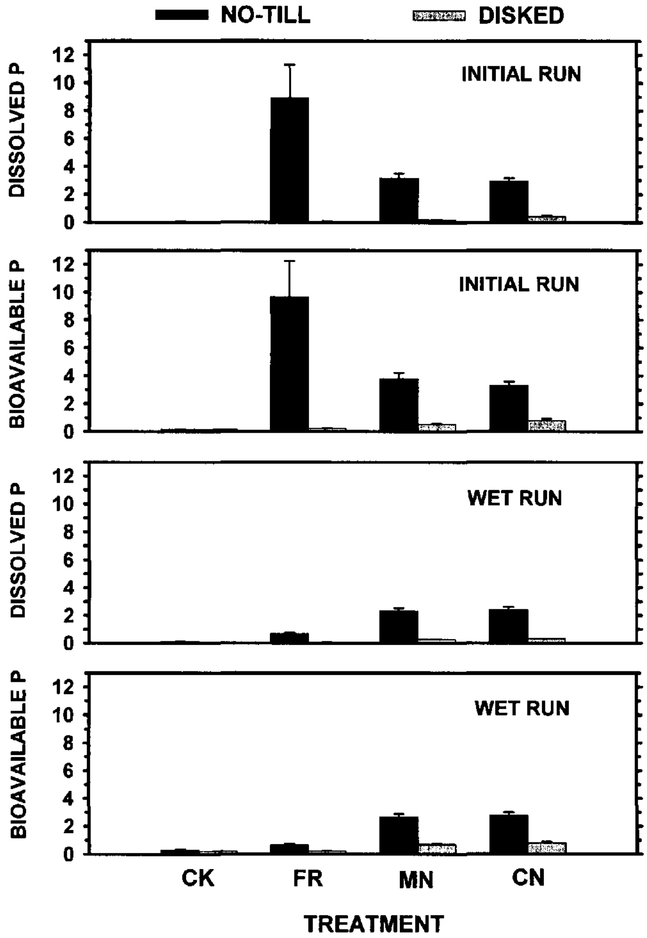

Fig. 4. Runoff concentration (mg L^{-1}) of dissolved and bioavailable P for four fertility treatments and two tillage systems during the initial and wet rainfall simulation runs on the wheat residue study. CK is check, FR is fertilizer, MN is manure for corn N needs, and CN is compost for corn N needs. Vertical bars are standard errors (2 SE indicates 0.95 and 1.55 SE indicates 0.90 probability level).

Wheat Residue Study

Slope varied from 4 to 7% on individual plots within the wheat residue study, while the mean slope was 6%. Residue cover ranged from 36 to 84%, and 11 to 24% on the no-till and disked plots, respectively. Mean residue cover was 65% for the no-till and 17% for the disked treatment. The single disking operation reduced mean residue cover by 74%.

Runoff concentrations of DP, BAP, and NH_4–N were greater for no-till than the disked treatment during both simulated rainfall runs (Tables 7 and 8). However, the concentrations of total P and particulate P were less for no-till than disked conditions (Tables 7 and 8) indicating that greater erosion from the disked soil (Gilley and Eghball, 1998) resulted in more particulate and total P being carried by runoff. Total N concentration was not influenced by the tillage systems during either simula-

Table 9. Tillage by treatment interaction means for runoff particulate P (PP), nitrate–N, ammonium–N, total N, electrical conductivity (EC), and pH during both simulation runs on a field with wheat residue in 1997.

Treatment	Tillage	PP	NO_3–N†	NH_4–N	Total N	EC	pH
		mg L^{-1}				d S m^{-1}	
Initial run							
Check	No-till	4.0	22.8	0.1	120.5	0.74	7.4
Check	Disked	6.0	24.7	0.1	89.7	0.71	7.4
Compost	No-till	2.5	47.2	10.4	100.8	1.17	7.2
Compost	Disked	6.0	26.9	1.4	102.7	0.78	7.4
Fertilizer	No-till	0.0	24.9	15.8	94.8	0.82	7.4
Fertilizer	Disked	5.2	28.6	1.6	162.1	0.74	7.4
Manure	No-till	1.2	26.6	12.6	115.3	1.09	7.2
Manure	Disked	5.0	22.4	0.6	80.7	0.73	7.4
Wet run							
Check	No-till	4.5	22.6	0.1	92.8	0.75	7.5
Check	Disked	6.5	23.3	0.2	83.3	0.74	7.3
Compost	No-till	1.1	35.8	6.2	84.5	0.99	7.3
Compost	Disked	6.1	25.0	0.9	88.7	0.81	7.3
Fertilizer	No-till	3.0	26.5	5.6	106.8	0.80	7.5
Fertilizer	Disked	8.1	20.7	3.7	75.4	0.72	7.3
Manure	No-till	0.8	23.7	7.2	91.3	0.94	7.2
Manure	Disked	7.3	23.3	1.0	85.6	0.79	7.3

† Irrigation water had an average NO_3–N concentration of 23 mg L^{-1}.

tion run (Tables 7 and 8). There were significant interactions between tillage and treatment for all parameters except total P during both runs (Tables 7 and 8). Runoff concentrations of DP and BAP for the fertilizer treatment were much greater during the initial run than the wet run (Fig. 4). This trend was similar to the study on sorghum residue indicating that P loss from manure and compost will be longer and possibly larger than fertilizer application because of the greater amounts of P applied with manure or compost than chemical fertilizer. Concentrations of DP and BAP were greater for no-till than the disked condition for the manure, compost, and fertilizer treatments (Fig. 4). Similar to the findings in the sorghum residue study, runoff DP concentration was <1 mg L^{-1} for all treatments in the disked system during both simulation runs. Runoff concentrations of total P, NO_3–N, and EC were greater for compost than manure during the initial run (Table 7).

The runoff EC values for all four treatments were lower for disked than no-till but the magnitudes of the differences between tillage systems were greater for the manure and compost than fertilizer or check treatments during both runs (Table 9). This indicates greater salt content of runoff from manure or compost-amended soil than fertilized soil, especially under no-till condition. Runoff PP concentrations were greater for disked than no-till for all treatments during both runs, but the differences between tillage systems were less for the check than the other treatments (Table 9). Runoff NO_3–N concentration for compost was greater for no-till than the disked system during both simulation runs while NO_3–N concentration of runoff from other treatments contained similar amounts of NO_3–N for both tillage systems (Table 9). Unlike the sorghum residue study, the high soil NO_3–N concentration of this field did not increase runoff NO_3–N concentration of the disked treatment as compared with the no-till. Runoff ammonium–N concentration was greater than the critical 2.5

Table 10. Effects of tillage and treatment on total amounts of dissolved P (DP), bioavailable P (BAP), particulate and total P, nitrate–N, total N, and ammonium–N in runoff during initial and wet simulation rainfall runs in a field with winter wheat residue in 1997.

Variable	DP	BAP	Particulate P	Total P	NO_3–N†	NH_4–N	Total N
	kg ha^{-1}						
Initial Run							
Tillage							
No-till	0.35 a	0.39 a	0.18 b	0.39 a	2.57 a	0.80 a	9.19 a
Disked	0.02 b	0.04 b	0.57 a	0.58 a	2.46 a	0.06 b	10.83 a
Treatment							
Compost	0.16 ab	0.19 ab	0.45 ab	0.61 a	3.61 a	0.53 ab	10.11 a
Manure	0.10 ab	0.14 ab	0.31 ab	0.41 a	2.04 b	0.39 ab	8.39 a
Fertilizer	0.46 a	0.50 a	0.16 b	0.34 a	1.94 b	0.79 a	10.25 a
Check	0.01 b	0.02 b	0.57 a	0.58 a	2.45 ab	0.01 b	11.30 a
Wet Run							
Tillage							
No-till	0.34 a	0.39 a	0.59 b	0.93 b	6.94 b	1.20 a	23.64 b
Disked	0.07 b	0.19 b	2.81 a	2.88 a	9.19 a	0.49 b	32.59 a
Treatment							
Compost	0.40 a	0.54 a	1.33 a	1.73 a	9.80 a	1.05 a	28.79 a
Manure	0.29 b	0.40 b	1.48 a	1.77 a	6.73 b	0.92 a	24.29 a
Fertilizer	0.11 c	0.14 c	2.01 a	2.12 a	7.87 b	1.38 a	29.43 a
Check	0.03 d	0.08 c	1.98 a	2.01 a	7.88 b	0.03 b	29.97 a

† Within tillage or treatment of each run, values with different letters are significantly different at 0.10 probability level based on Duncan's Multiple Range Test.

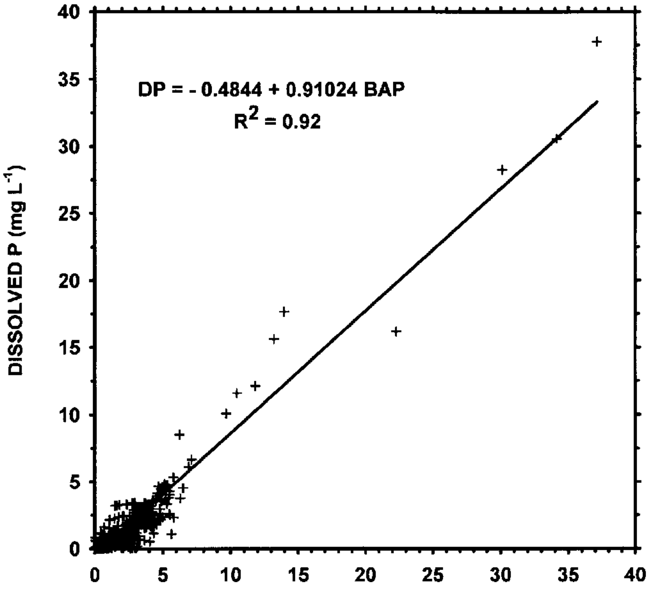

Fig. 5. Relationship between dissolved P and bioavailable P for both sorghum and wheat residue studies and the two simulation runs.

mg L^{-1} for the manure, compost, and fertilizer treatments in no-till during both simulation runs.

Runoff concentration of DP, BAP, and ammonium–N, and EC and pH levels from the soil with sorghum residue were similar to those from the soil with wheat residue, but runoff total P concentration was greater from the soil with sorghum residue than that with wheat residue. This could have been caused by greater erosion from the soil with sorghum residue than the soil with wheat residue (Gilley and Eghball, 1998).

Total runoff loads of N and P during both simulation runs is given in Table 10. The trends for the load of nutrients in runoff were similar to those of concentration for all parameters except for NO_3 during both simulation runs and total N and PP during wet run (Tables 7, 8, and 10).

When data from both simulation runs and the two experiments were combined, there was a significant correlation between runoff DP and BAP levels (Fig. 5). Dissolved P accounted for about 91% (slope = 0.91) of the BAP in runoff indicating the importance of DP in water pollution.

SUMMARY

Nitrogen-based manure or compost application to no-till soil with sorghum or wheat residue can cause a significant increase in runoff concentration of dissolved P, bioavailable P, and NH_4–N as compared to the disked condition. Manure and compost applied and disked into the soil did not increase runoff concentration of dissolved and bioavailable P, but increased runoff concentration of total P. Phosphorus-based manure or compost application resulted in runoff dissolved P concentrations that were $\leq$1 mg L^{-1}, the critical runoff DP concentration. Electrical conductivity values were greater for manure and compost as compared to the fertilizer and check treatments indicating greater loss of salt from these organic sources. Dissolved P constituted 91% of the bioavailable P in runoff. Phosphorus-based manure and compost application, with additional N as fertilizer, had acceptable runoff P loss, and were found to produce corn grain yields similar to N-based manure, compost, or fertilizer applications (Eghball and Power, 1999b). Nitrogen-based manure and compost application under no-till conditions resulted in runoff DP concentration that was greater than the critical 1 mg L^{-1}. Disked N-based manure or compost application resulted in DP concentrations <1 mg L^{-1}. Runoff concentration of total P was greater for the soil with sorghum than wheat residue. This reflects greater erosion from the soil with sorghum residue than the soil with wheat residue. Phosphorus-based manure and compost application seems to be an agronomically and environmentally sound management system.

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